Monitoring Stink Bugs (Hemiptera: Pentatomidae) in Mid-Atlantic Apple and Peach Orchards

T. C. LESKEY[1] AND H. W. HOGMIRE[2]

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ABSTRACT Pyramid traps coated with "industrial safety yellow" exterior latex gloss enamel paint and baited with *Euschistus* spp. aggregation pheromone, methyl (2*E*,4*Z*)-decadienoate captured more stink bugs than all other baited and unbaited trap types in both apple and peach orchards in 2002 and 2003. Commercial sources of dispensers of methyl (2*E*,4*Z*)-decadienoate deployed in association with pyramid traps had a significant impact on trap captures. Captures in pyramid traps were four-fold greater when baited with lures from IPM Technologies, Inc. (Portland, OR) than with lures from Suterra (Bend, OR). Variation in yellow pyramid trap color ("industrial safety yellow" and "standard coroplast yellow") and material (plywood, plastic, and masonite) did not affect trap captures. Brown stink bug was the predominant species captured (58%), followed by dusky stink bug, *Euschistus tristigmus* (Say) (20%); green stink bug, *Acrosternum hilare* (Say) (14%); and other stink bugs (*Brochymena* spp. and unidentified nymphs) (8%). Captures in baited pyramid traps were significantly correlated with tree beating samples in both managed and unmanaged apple orchards and with sweep netting samples in the unmanaged apple orchard. However, problems associated with trapping mechanisms of pyramid trap jar tops and jar traps likely resulted in reduced captures in baited traps. Improved trapping mechanisms must be established to develop an effective monitoring tool for stink bugs in mid-Atlantic orchards.

KEY WORDS *Euschistus servus*, *E. tristigmus*, *Acrosternum hilare*, monitoring, insect traps

A NUMBER OF SPECIES OF stink bugs are major pests of peach, inflicting catfacing, scarring, dimpling, and water-soaked and gummosis-type injuries (Hogmire 1995). Although stink bugs are considered pests of apple in the western United States (Beers et al. 1993, Ohlendorf 1999), they have not achieved this status in eastern orchards. However, stink bug injury in eastern apple orchards is likely underestimated due to the similarity in appearance to and potential for misdiagnosis as the physiological disorders cork spot (Brown 2003) and bitter pit (Ohlendorf 1999). The potential for stink bugs to become serious pests of apple could be influenced by further cancellations or restrictions of current broad-spectrum insecticides as a result of the Food Quality Protection Act. As narrow-spectrum chemistries replace broad-spectrum insecticides for control of key insect pests in both peach and apple, it is likely that stink bugs will emerge as an increasing annual threat. To effectively manage stink bugs in a narrow-spectrum, reduced-spray environment, it is imperative that treatments for stink bugs be triggered by detection of increases in abundance or activity.

Monitoring and management of stink bugs is especially challenging as they are highly mobile, polyphagous pests (McPherson and McPherson 2000). In California, beating tray samples, examination of broadleaf weed hosts, and incidence of fruit injury are recommended to determine whether action thresholds are exceeded (Ohlendorf 1999). Similarly, beating tray and sweep net samples as well as incidence of fruit injury are recommended in the eastern United States, although no action thresholds exist for determining need for and timing of insecticide applications (Hogmire 1995).

The ability to monitor *Euschistus* spp. was improved by the identification of an aggregation pheromone, methyl (2*E*,4*Z*)-decadienoate (Aldrich et al. 1991). Plastic jar traps became commercially available in 1996 for use with the pheromone to monitor *Euschistus* spp., but data on their performance remain unpublished. Tube traps possessing wire mesh cone funnels at either end and baited with methyl (2*E*,4*Z*)-decadienoate failed to capture *E. conspersus* Uhler in a Washington study (Krupke et al. 2001), but they are recommended as a monitoring tool for this same species in California (Ohlendorf 1999). Pyramid traps baited with methyl (2*E*,4*Z*)-decadienoate have been the most common tool evaluated for monitoring stink bugs in pecans (Mizell and Tedders 1995, Mizell et al.

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[1] USDA–ARS, Appalachian Fruit Research Station, 2217 Wiltshire Rd., Kearneysville, WV 25430.

[2] West Virginia University, Tree Fruit Research and Education Center, P.O. Box 609, Kearneysville, WV 25430

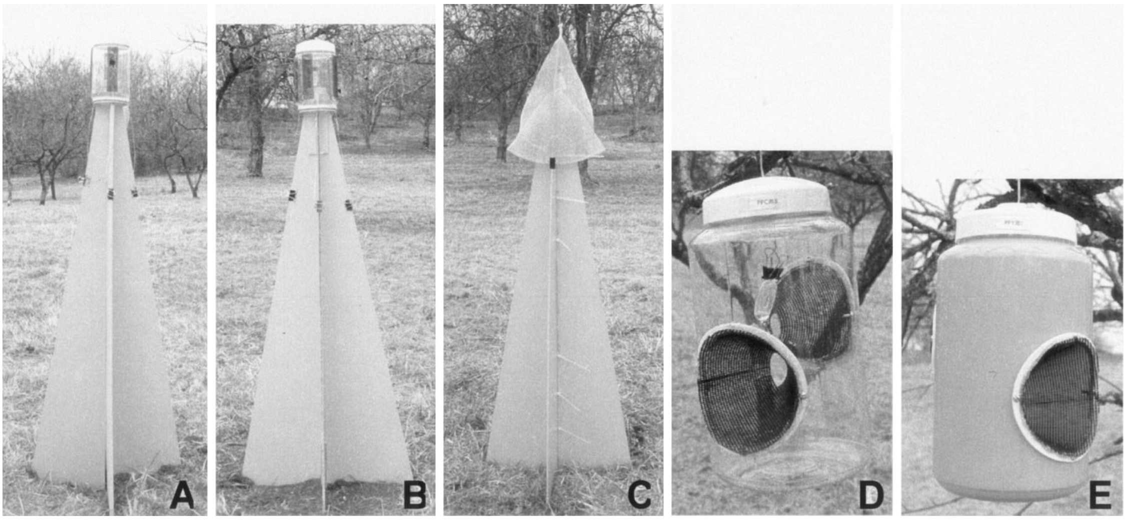

Fig. 1. Yellow plywood (A), plastic (B), and masonite (C) pyramid traps, and clear (D) and yellow (E) jar traps used for stink bug monitoring.

1996) and peaches (Johnson et al. 2002) in the southern United States. Mizell and Tedders (1995) found that more stink bugs were captured by pyramid traps coated with industrial safety yellow exterior latex gloss enamel paint than by pyramid traps coated with light and dark green, black, or covered with aluminum foil. Yellow pyramid traps baited with methyl (2*E*,4*Z*)-decadienoate were used to assess seasonal occurrence and canopy distribution of brown [*Euschistus servus* (Say)] and dusky [*Euschistus tristigmus* (Say)] stink bugs in pecan orchards (Cottrell et al. 2000).

However, no information exists regarding brown or dusky stink bug responses to baited jar or pyramid traps in apple and peach orchards in the mid-Atlantic and northeastern United States. Therefore, we evaluated paired baited [with methyl (2*E*,4*Z*)-decadienoate] and unbaited pyramid and jar traps in commercial and unsprayed apple and peach orchards in 2002 and 2003. We also documented the response of green stink bug, *Acrosternum hilare* (Say), to these same trap treatments because it is an economically important species of tree fruit in the mid-Atlantic region (Hogmire 1995). In 2003, we also conducted tree beating and sweep net sampling, compared two commercially available pheromone lures in association with pyramid traps, and conducted experiments to evaluate effectiveness of the trapping mechanisms of jar and pyramid traps.

Materials and Methods

Trapping Experiments 2002. Four study sites were used to evaluate stink bug response to traps in 2002. Commercial orchards of 1.2-ha Rome apples on M7 rootstock planted in 1989 and 3.2-ha Newhaven peaches on Lovell rootstock planted in 1988 were located in Hampshire County, West Virginia. Two additional sites planted in 1997 consisted of adjoining apple (Granny Smith on EMLA 26 and Empire on EMLA 9/EMLA 111 rootstocks) and peach (Loring on Lovell rootstock) orchards of 1 ha each and were located at the USDA–ARS Appalachian Fruit Research Station (USDA–AFRS) in Jefferson County, West Virginia. Each orchard bordered a wood lot, hedge row, or rock break. The commercial orchards received applications of crop protection chemicals for arthropod pests according to standard practices followed in the mid-Atlantic (Anonymous 2002). The peach orchard received applications of esfenvalerate, methomyl, and permethrin. The apple orchard, which was under a Risk Avoidance and Mitigation Program, received applications of indoxacarb, methoxyfenozide, pyridaben, and thiamethoxam. There was no arthropod pest management program in the experimental orchards at the USDA–AFRS.

Two trap types were used. Jar traps similar to those available from Scenturion, Inc. (Clinton, WA) (now Suterra, Bend, OR) were constructed from 3.8-liter clear plastic Rubbermaid jars with screw-cap lids (Fig. 1D). Two off-setting 10-cm-diameter holes were cut in opposite sides of the jars, and a poly(vinyl chloride) (PVC) gasket (2 mm in thickness, 7 mm in width, and outside diameter of 11.4 cm) was cut from 10.2-cm-diameter PVC pipe and attached around the perimeter of each hole with four bolts and nuts. Plastic pet screening (New York Wire Co., Mt. Wolf, PA) was formed into a cone and fastened with hot glue, with each cone positioned flush with the hole opening and secured with hot glue to the PVC gasket. Cones projected to the center of the jar trap with an internal opening of 15 by 30 cm.

Pyramid traps (Mizell and Tedders 1995, Mulder et al. 1997) were constructed of two panels of 1.3-cm-thick plywood that were painted with two coats of exterior latex gloss enamel paint, color-matched to professional industrial safety yellow (Mizell and Tedders 1995) (Fig. 1A). Each panel was 1.22 m in height, 52 cm in width at the base, and 7 cm in width at the top. A slit extending from the base of one panel and from the top of another was cut 61 cm in length by 1.5 cm in width. A 5-mm hole was bored into each corner of the panel with the slit at the top, to which was attached a piece of wire and 25-cm-long galvanized nail for anchoring the traps to the ground. A 1.9-liter clear plastic Rubbermaid jar with screw-cap lid was prepared for placement on the top of each pyramid base. The base of each jar was cut away and a PVC gasket (7 mm in thickness, 11 mm in width, and outside diameter of 11.4 cm) was cut from 10.2-cm-diameter PVC pipe and secured around the perimeter with hot glue. A wire screen funnel was inserted and attached at the wide end to the jar with hot glue. The jar was vented around the perimeter and in the lid with openings covered by plastic pet screening attached with hot glue. The jar was placed on top of the pyramid so that the support braces of the funnel were positioned against the inserted top baffles of the pyramid trap. The jar was secured to the panels of the pyramid with spring clips attached to wires extending from four holes in the base of the jar.

Three replications of four treatments were established at each orchard site: baited and unbaited pyramid and jar traps. Traps were baited with lures containing 100 mg of methyl (2*E*,4*Z*)-decadienoate (Scenturion, Inc., now available from Suterra) that were suspended inside the jars from the lids. All traps contained one-fourth piece of an Atroban Extra insecticide ear tag (Schering-Plough Animal Health Corporation, Union, NJ) (Cottrell 2001) impregnated with 10% permethrin and 13% piperonyl butoxide attached with wire under the jar lid. Traps were installed on 30 May in the commercial orchards and on 6 June in experimental orchards. All traps were installed within the border row with pyramid traps located between trees and jar traps suspended from horizontal limbs at head height within the tree canopy. Within each replicate, trap location was randomly assigned and traps were at least 4.9 m apart. Traps were inspected weekly through the end of August or September in peach and apple orchards, respectively, with lures and ear tags replaced every 3 wk. Stink bugs were collected in labeled vials of 70% ethanol and identified with taxonomic keys found in McPherson and McPherson (2000). Trap capture data were accumulated across weeks and subjected to nontransformed analyses as the homogeneity of variances assumption based on the Brown and Forsythe test was met in all cases. Data were analyzed using the GLM procedure (SAS Institute 2001) to construct analysis of variance (ANOVA) tables for cumulative trap captures recorded over the entire season. Each model included the following class variables: replicate and trap type. If the effect of replicate was not significant, it was dropped from the model. When the GLM indicated significant differences, multiple comparisons were calculated using Tukey's honestly significant difference (HSD) at $\alpha = 0.05$.

Trapping Experiments 2003. Four study sites also were used for trap evaluation in 2003. In addition to the commercial apple and peach orchards used in 2002, two abandoned orchards were included that consisted of 3.6-ha Empire and Gala apples on M.26 rootstock planted in 1994 in Berkeley County, West Virginia; and 0.17-ha Loring peaches on Lovell rootstock planted in 1989 in Jefferson County, West Virginia. Arthropod pests were managed in the commercial orchards with the same chemicals used in 2002.

Five traps were evaluated, including those evaluated in 2002 plus two additional pyramid trap types and one additional jar trap. One pyramid trap, identical to the plywood version used in 2002, was constructed of 6-mm-thick plastic (coroplast, AIN Plastics, Virginia Beach, VA) and coated with industrial safety yellow paint (Fig. 1B). The second new pyramid trap type was constructed of four masonite panels (3 mm in thickness, 1.22 m in height, 26 cm in width at the base, 3 cm in width at the top) that were joined together with cable ties threaded through six holes along the inner margin of each panel (Mizell and Tedders 1995) and coated with industrial safety yellow paint (Fig. 1C). Masonite traps were anchored with a 6-mm-diameter, 19-cm-long metal rod that was driven into the ground in the center of the pyramid. Plywood and plastic pyramids were topped with plastic jars similar to those used in 2002. For the masonite pyramid, the collection device consisted of a two-layer cone-shaped aluminum screen cage that was attached with spring clips to the top of the pyramid base. The second jar trap was identical to the one used in 2002, except that it was coated on the inside with industrial safety yellow paint (Fig. 1E).

Three replications of five baited and unbaited treatments were set up at each orchard. Baited traps were provisioned with lures containing 200+ mg of methyl (2*E*,4*Z*)-decadienoate (IPM Technologies, Inc., Portland, OR). All traps were provisioned with one-fourth piece of ear tag as in 2002. Traps were installed in a border row adjacent to woods of the two apple orchards and the commercial peach orchard and throughout the abandoned peach orchard. Pyramid traps were positioned between trees and jar traps were hung from horizontal branches at head height within tree canopies. Within each replicate, trap location was randomly assigned and traps were at least 4.9 m apart in commercial orchards, and 6.0 and 7.4 m apart in the abandoned apple and peach orchard, respectively. Traps were installed on 28 March and 3 April in abandoned and commercial orchards, respectively. Traps were inspected weekly through the end of August or mid-October in peach and apple orchards, respectively, with lures and ear tags replaced every 6 wk. Stink bugs were preserved and identified, and data analyzed as in 2002.

Pyramid Trap Color and Lure Comparison. The effects of pyramid trap color and lure type on stink bug capture were evaluated. Plastic pyramid traps painted industrial safety yellow, as described above, were compared with pyramid traps identically constructed from 3-mm-thick yellow plastic available from the same manufacturer and referred to here as standard coroplast yellow. Spectral reflectance of industrial safety yellow paint and standard coroplast yellow

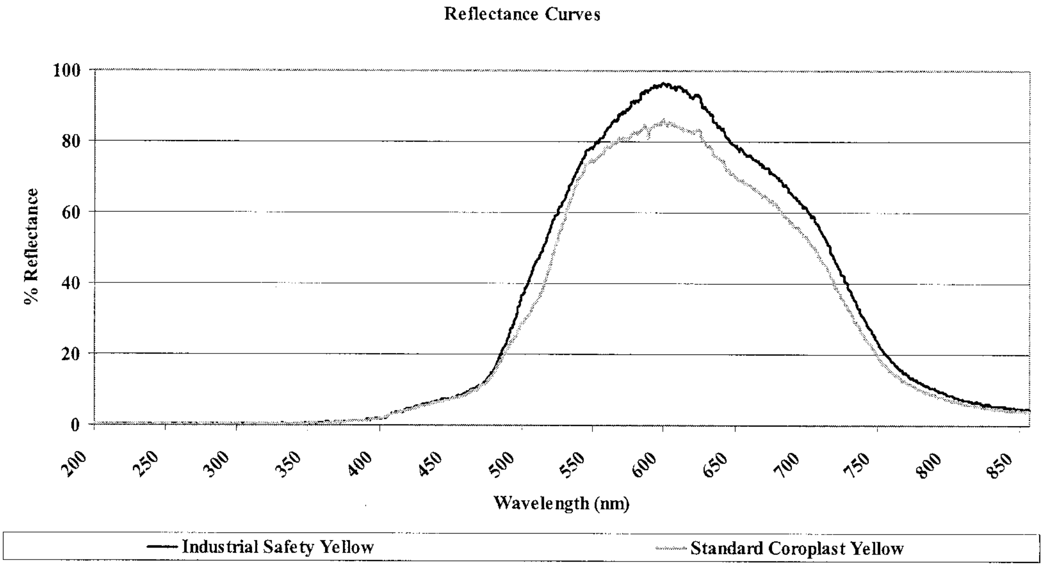

Fig. 2. Spectral reflectance curves obtained from industrial safety yellow paint and standard coroplast yellow.

were determined using a StellarNet EPP 2000C fiber-optic spectrometer fitted with an IC2-UV/visible light integrating sphere, and spectral reflectance curves were generated using SpectraWiz (StellarNet, Tampa, FL) (Fig. 2). Each pyramid trap type was baited with IPM Technologies, Inc., lures and an additional treatment of industrial safety yellow pyramid traps was baited with Suterra lures used in 2002 studies. Three replications of each trap treatment were provisioned with one-fourth piece of ear tag and installed between trees in the border row, adjacent to a woods, of a 1.2-ha Cresthaven peach orchard from 12 June to 28 August (11 wk), and a 1.2-ha Rome apple orchard from 28 August to 15 October (7 wk) in Hampshire County, West Virginia. Again trap location was randomly assigned within each replication and traps were at least 4.9 m apart. Stink bugs were collected weekly, as described above, with lures and ear tags replaced when traps were moved from peach to apple. Trap capture data were accumulated across weeks and subjected to nontransformed analyses as the homogeneity of variances assumption based on the Brown and Forsythe test was met in all cases. Data were analyzed using the GLM procedure (SAS Institute 2001) to construct ANOVA tables for cumulative trap captures recorded over the entire season. Each model included the following class variables: replicate and trap type. If the effect of replicate was not significant, it was dropped from the model. When the GLM indicated significant differences, multiple comparisons were calculated using Tukey's HSD at $\alpha = 0.05$.

Tree and Weed Sampling. Apple and peach trees and weeds on the orchard borders were sampled for stink bugs in the same commercial and abandoned orchards where trapping was conducted in 2003. Ten randomly selected trees per orchard within tree rows used in trapping studies were sampled on two opposite sides by tapping branches three times with a padded pole and collecting dislodged stink bugs on a 1.8 by 2.4-m framed sheet supported by legs 50 cm above the ground. Flowering weeds on the orchard borders were sampled with sweep nets in each of three areas or replicates, with each replicate consisting of two 25–180° sweeps across the ground cover (Atanassov et al. 2002). Tree and weed sampling began on 1 May, with biweekly samples taken on the same dates traps were inspected for the remainder of the season. All samples were taken between 0930 and 1430 hours. Stink bugs were collected and identified as described above. Pearson's correlation coefficients were calculated to determine whether the average biweekly capture per baited pyramid trap was correlated with average biweekly capture per replicate obtained from tree beating and from weed sweeping sampling methods in each orchard.

Trapping Mechanism Studies. A study was conducted at the West Virginia University Kearneysville Tree Fruit Research and Education Center in 2003 to determine whether pyramid trap jar tops and jar traps were effective at retaining or killing captured brown stink bugs. Pyramid trap jar tops and clear jar traps were provisioned with an IPM Technologies, Inc., lure and one-fourth piece of insecticide ear tag. A sleeve of insect netting was installed over the bottom pyramid trap jar openings and over the entire jar traps. Either six female or six male brown stink bugs were released into five pyramid trap jar tops and five jar traps. Jar tops and jar traps were suspended from a horizontal high tensile wire between trees in a border row of a block of Rome apples. Pyramid trap jar tops were installed on 8 September and inspected daily until 15 September. Jar traps were installed on 23 September and inspected daily through 26 September for males and 28 September for females because on these dates

Table 1. Cumulative mean number ± SE of brown, dusky, green, and total stink bugs captured in each trap type in apple and peach orchards in 2002

Trap type	Commercial apple				Experimental apple			
	Brown	Dusky	Green	Total	Brown	Dusky	Green	Total
Baited pyramid	12.0 ± 3.1a[a]	3.7 ± 0.9a	3.3 ± 0.3a	20.0 ± 3.2a	2.7 ± 0.7a	0.7 ± 0.3a	0.0 ± 0.0a	4.0 ± 1.5a
Baited clear jar	6.0 ± 0.6a	1.3 ± 0.3a	1.3 ± 0.7ab	9.0 ± 0.6b	1.7 ± 0.9a	0.0 ± 0.0a	0.0 ± 0.0a	1.7 ± 0.9a
Unbaited pyramid	2.3 ± 1.3b	1.7 ± 1.2a	2.3 ± 0.3a	7.0 ± 2.0bc	1.0 ± 0.6a	0.0 ± 0.0a	0.0 ± 0.0a	1.3 ± 0.6a
Unbaited clear jar	0.3 ± 0.3b	0.3 ± 0.3a	0.0 ± 0.0b	0.7 ± 0.7c	0.3 ± 0.3a	0.3 ± 0.3a	0.0 ± 0.0a	0.7 ± 0.3a
	Commercial peach				Experimental peach			
Baited pyramid	3.7 ± 1.2a	1.7 ± 0.9a	1.0 ± 0.0a	7.3 ± 2.6a	1.3 ± 0.9a	0.3 ± 0.3a	0.0 ± 0.0a	1.7 ± 0.9a
Baited clear jar	0.0 ± 0.0b	1.0 ± 0.6a	0.0 ± 0.0a	1.0 ± 0.6ab	1.3 ± 0.9a	0.3 ± 0.3a	0.0 ± 0.0a	1.7 ± 0.9a
Unbaited pyramid	1.0 ± 1.0ab	0.3 ± 0.3a	1.0 ± 1.0a	2.7 ± 1.3ab	0.0 ± 0.0a	0.0 ± 0.0a	0.0 ± 0.0a	0.0 ± 0.0a
Unbaited clear jar	0.0 ± 0.0b	0.0 ± 0.0a	0.0 ± 0.0a	0.0 ± 0.0b	0.0 ± 0.0a	0.0 ± 0.0a	0.0 ± 0.0a	0.0 ± 0.0a

[a] Means within a column for each crop followed by the same letter are not significantly different ($\alpha = 0.05$; Tukey's HSD test).

100% of all released individuals had escaped or died. Escaped and dead stink bugs were removed upon inspection. Data were analyzed using one-way ANOVA with mean separation by Tukey's HSD test at $\alpha = 0.05$ level (SAS Institute 2001) to determine whether there were significant differences among the number of individuals that had escaped, died, or were alive at the conclusion of each experimental period.

Results

Trapping Experiments 2002. In the commercial apple orchard, the GLM was significant ($F = 25.30$; df = 5, 6; $P = 0.0006$). The effect of replicate ($P = 0.04$) and trap type ($P = 0.0003$) were significant. Significantly more stink bugs were captured in baited plywood pyramid traps compared with any other trap type (Table 1). A similar pattern of stink bug capture was observed in the experimental apple orchard, but the GLM was not significant and there were no significant differences among the trap types ($F = 2.61$; df = 3, 8; $P = 0.1232$) (Table 1). In the commercial peach orchard, the GLM was significant ($F = 4.75$; df = 3, 8; $P = 0.0348$) with significantly greater captures in baited plywood pyramid traps compared with unbaited jar traps (Table 1). In the experimental peach orchard, the GLM was not significant and there were no significant differences in stink bug capture among trap types ($F = 2.38$; df = 3, 8; $P = 0.1453$) (Table 1). A total of 186 stink bugs were captured in apple and peach orchards at both locations. Overall captures per trap type were as follows: 57% in baited pyramid traps, 18% in unbaited pyramid traps, 23% in baited jar traps, and 2% in unbaited jar traps.

Total trap capture by species across all sites consisted predominantly of brown stink bug (55%), followed by dusky (20%), green (16%), and other stink bugs (*Brochymena* spp. and unidentified nymphs, 9%). The GLMs for capture of brown stink bugs were significant in commercial apple ($F = 9.09$; df = 3, 8; $P = 0.0059$) and peach ($F = 4.91$; df = 3, 8; $P = 0.0320$) orchards but not significant in experimental apple ($F = 2.38$; df = 3, 8; $P = 0.1456$) and peach ($F = 1.52$; df = 3, 8; $P = 0.2813$) orchards. Significantly greater captures of brown stink bugs were recorded in baited plywood pyramid and clear jar traps compared with unbaited traps in the commercial apple orchard, and in baited plywood pyramid traps compared with unbaited jar traps in the commercial peach orchard (Table 1).

The GLMs for capture of dusky stink bugs were not significant in commercial apple ($F = 3.20$; df = 3, 8; $P = 0.0838$), commercial peach ($F = 1.79$; df = 3, 8; $P = 0.2272$), experimental apple ($F = 1.83$; df = 3, 8; $P = 0.2192$), and experimental peach ($F = 0.67$; df = 3, 8; $P = 0.5957$) orchards, although the greatest number captured were in baited pyramid traps in commercial apple and peach orchards, and the experimental apple orchard (Table 1).

The GLM for capture of green stink bugs in the commercial apple orchard was significant ($F = 12.17$; df = 3, 8; $P = 0.0024$), with significantly more captures in baited plywood pyramid traps compared with unbaited jar traps (Table 1). The GLM for capture of green stink bugs in the commercial peach orchard was not significant ($F = 1.33$; df = 3, 8; $P = 0.3300$), and no green stink bugs were captured in the experimental apple and peach orchards (Table 1).

A higher percentage of females than males of both brown and dusky stink bugs were captured in baited plywood pyramid (62 and 69%) and baited clear jar traps (58 and 62%), whereas captures in unbaited plywood pyramid traps were predominantly female for brown (70%) and male for dusky (62%). Unbaited jars captured an equal percentage of each sex, but only four specimens were captured. For green stink bug, similar percentages of males and females were captured in baited plywood pyramids, whereas females were predominant in both unbaited plywood pyramids (70%) and baited clear jars (75%). The combined capture of stink bugs by sex across all trap types averaged 38% males and 62% females for both brown and dusky stink bugs, and 31% males and 69% females for green stink bug.

Trapping Experiments 2003. In the commercial apple orchard, the GLM was significant ($F = 3.16$; df = 9, 20; $P = 0.0155$), and although Tukey's HSD failed to indicate differences among trap types, more stink bugs were captured in baited plywood, plastic, and masonite pyramid traps compared with all other baited and unbaited traps (Table 2). The GLM was significant for the commercial peach orchard ($F = 9.53$; df = 9, 20;

Table 2. Cumulative mean number ± SE of brown, dusky, green, and total stink bugs captured in each trap type in apple and peach orchards in 2003

Trap type	Commercial apple				Abandoned apple			
	Brown	Dusky	Green	Total	Brown	Dusky	Green	Total
Baited plywood[a]	27.7 ± 9.1a[b]	9.7 ± 3.5a	6.3 ± 1.5a	49.7 ± 8.6a	33.3 ± 6.7a	4.7 ± 1.8ab	0.3 ± 0.3a	41.7 ± 5.8a
Baited Plastic[a]	25.0 ± 6.1a	8.7 ± 1.2a	12.7 ± 5.8a	54.7 ± 16.7a	29.7 ± 7.9a	4.3 ± 1.8ab	0.3 ± 0.3a	37.7 ± 10.0a
Baited Masonite[a]	24.7 ± 11.2a	10.7 ± 3.2a	40.0 ± 30.5a	79.7 ± 47.7a	27.0 ± 7.6a	12.7 ± 5.7a	0.0 ± 0.0a	41.0 ± 13.0a
Baited Clear[c]	2.0 ± 1.2b	1.3 ± 0.3ab	1.0 ± 0.0a	4.3 ± 1.2a	4.0 ± 1.2b	4.3 ± 1.2ab	0.3 ± 0.3a	9.0 ± 1.5b
Baited Yellow[c]	2.0 ± 1.0b	3.3 ± 1.9ab	2.0 ± 0.6a	7.3 ± 2.8a	2.0 ± 0.0b	1.3 ± 0.9b	0.0 ± 0.0a	3.7 ± 1.2b
Unbaited plywood	0.0 ± 0.0b	0.3 ± 0.3b	0.3 ± 0.3a	4.3 ± 3.8a	2.7 ± 0.7b	0.0 ± 0.0b	0.0 ± 0.0a	2.7 ± 0.7bc
Unbaited Plastic	0.7 ± 0.3b	1.0 ± 1.0b	1.0 ± 0.6a	3.3 ± 1.9a	2.7 ± 0.7b	0.3 ± 0.3b	0.0 ± 0.0a	4.3 ± 0.9b
Unbaited Masonite	1.0 ± 1.0b	2.3 ± 1.9ab	1.7 ± 0.9a	5.0 ± 2.1a	3.3 ± 0.9b	3.7 ± 2.7ab	0.3 ± 0.3a	8.0 ± 3.0b
Unbaited Clear	0.0 ± 0.0b	0.3 ± 0.3b	0.0 ± 0.0a	0.3 ± 0.3a	0.0 ± 0.0b	0.0 ± 0.0b	0.0 ± 0.0a	0.0 ± 0.0c
Unbaited Yellow	0.0 ± 0.0b	0.0 ± 0.0b	0.0 ± 0.0a	0.0 ± 0.0a	0.3 ± 0.3b	0.0 ± 0.0b	0.0 ± 0.0a	0.3 ± 0.3bc
	Commercial peach				Abandoned peach			
Baited plywood	13.0 ± 1.2a	4.3 ± 1.5ab	1.0 ± 0.6a	20.3 ± 2.8ab	8.3 ± 4.0abc	0.0 ± 0.0b	0.3 ± 0.3a	9.0 ± 4.2bc
Baited Plastic	22.3 ± 7.9a	7.0 ± 2.7a	1.0 ± 1.0a	31.7 ± 10.2a	10.7 ± 1.5ab	0.0 ± 0.0b	0.3 ± 0.3a	11.0 ± 1.7b
Baited Masonite	14.0 ± 3.5a	8.0 ± 1.2a	0.3 ± 0.3a	23.3 ± 5.8a	15.3 ± 2.6a	5.0 ± 0.6a	0.3 ± 0.3a	22.0 ± 3.2a
Baited Clear	1.0 ± 0.6b	0.7 ± 0.3b	0.3 ± 0.3a	2.0 ± 0.6bc	3.0 ± 3.0bc	0.7 ± 0.7b	0.0 ± 0.0a	3.7 ± 3.7bc
Baited Yellow	0.0 ± 0.0b	0.3 ± 0.3b	0.0 ± 0.0a	0.3 ± 0.3c	1.0 ± 1.0c	0.3 ± 0.3b	0.0 ± 0.0a	1.3 ± 0.9bc
Unbaited plywood	1.3 ± 0.3b	0.7 ± 0.7b	0.0 ± 0.0a	2.0 ± 0.6bc	1.0 ± 1.0c	0.0 ± 0.0b	0.0 ± 0.0a	1.3 ± 0.9bc
Unbaited Plastic	1.0 ± 0.6b	0.3 ± 0.3b	0.0 ± 0.0a	2.0 ± 0.6bc	0.7 ± 0.3c	0.0 ± 0.0b	0.0 ± 0.0a	0.7 ± 0.3bc
Unbaited Masonite	1.3 ± 0.3b	0.7 ± 0.7b	0.0 ± 0.0a	2.0 ± 1.0bc	1.7 ± 0.3c	0.3 ± 0.3b	0.0 ± 0.0a	2.0 ± 0.6bc
Unbaited Clear	0.0 ± 0.0b	0.0 ± 0.0b	0.0 ± 0.0a	0.0 ± 0.0c	0.0 ± 0.0c	0.0 ± 0.0b	0.0 ± 0.0a	0.0 ± 0.0c
Unbaited Yellow	0.0 ± 0.0b	0.3 ± 0.3b	0.0 ± 0.0a	0.0 ± 0.0c	0.0 ± 0.0c	0.0 ± 0.0b	0.0 ± 0.0a	0.0 ± 0.0c

[a] Pyramid trap type.
[b] Means within a column for each crop followed by the same letter are not significantly different ($\alpha = 0.05$; Tukey's HSD test).
[c] Jar trap type.

$P < 0.0001$) with significantly more stink bugs captured in baited plywood, plastic, and masonite pyramids compared with all other baited and unbaited traps (Table 2). Similarly, in the abandoned apple orchard, the GLM was significant ($F = 9.91$; df = 9, 20; $P < 0.0001$) and baited plywood, plastic, and masonite pyramid traps captured significantly more stink bugs than baited clear and yellow jar traps and all unbaited trap types (Table 2). In the abandoned peach orchard, the GLM was significant ($F = 10.79$; df = 9, 20; $P < 0.0001$), and baited masonite pyramid traps captured significantly more stink bugs than all other trap types (Table 2). In total, 1,475 stink bugs were captured in all locations by all trap types, with 73% of captures in apple orchards and 27% in peach orchards. Overall captures were as follows: 86% in baited plywood, masonite, and plastic pyramid traps; 8% in unbaited plywood, masonite, and plastic pyramid traps; 6% in baited clear and yellow jar traps; and <1% in unbaited clear and yellow jar traps.

Stink bug capture by species was similar for the abandoned orchards and the commercial peach orchard. As in 2002, brown stink bug predominated with a mean (range) capture of 71% (64–82%), followed by dusky at 21% (13–27%), green at 2% (1–3%), and other stink bugs at 6% (3–7%). The commercial apple orchard differed due to a greater abundance of green stink bugs, with brown, dusky, green, and other stink bugs representing 40, 18, 31, and 11% of total captures, respectively.

The GLMs for captures of brown stink bugs were significant and captures were significantly greater in all baited pyramid trap types compared with baited jar traps and all unbaited trap types in the commercial apple ($F = 5.92$; df = 9, 20; $P = 0.0005$), abandoned apple ($F = 10.98$; df = 9, 20; $P < 0.0001$), and commercial peach orchard ($F = 8.41$; df = 9, 20; $P <= 0.0001$) (Table 2). In the abandoned peach orchard, significantly more brown stink bugs were captured in the baited masonite pyramid traps compared with all other baited and unbaited trap types ($F = 8.09$; df = 9, 20; $P < 0.0001$).

For dusky stink bugs, the GLMs were significant in both the commercial ($F = 5.52$; df = 9, 20; $P = 0.0007$) and abandoned ($F = 3.16$; df = 9, 20; $P = 0.0153$) apple orchards, and significantly more dusky stink bugs were captured in all baited pyramid trap types compared with unbaited plywood and plastic pyramid traps and clear and yellow jar traps in the commercial apple orchard, and in baited masonite pyramid traps compared with baited yellow jar traps and unbaited plywood and plastic pyramid and clear and yellow jar traps in the abandoned apple orchard (Table 2). The GLM was significant ($F = 8.76$; df = 11, 18; $P < 0.0001$) for captures in commercial peach orchards, with the effect of trap ($P < 0.0001$) and replicate ($P = 0.0495$) being significant. Significantly more dusky stink bugs were captured in plastic and masonite pyramid traps than in baited jar traps and all unbaited trap types. In the abandoned peach orchard, the GLM was significant ($F = 24.06$; df = 9, 20; $P < 0.0001$) with significantly more dusky stink bugs captured in baited masonite pyramid traps than in all other trap types (Table 2).

Captures of green stink bugs were very low in general, and the GLMs were not significant for captures in the commercial apple ($F = 1.59$; df = 9, 20; $P = 0.1855$), abandoned apple ($F = 0.67$; df = 9, 20; $P =$

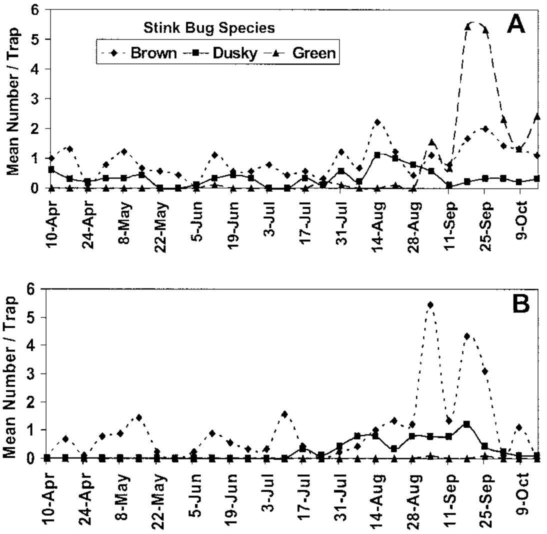

Fig. 3. Seasonal occurrence of brown, dusky, and green stink bugs as determined with baited pyramid traps in a commercial (A) and abandoned (B) apple orchard in 2003.

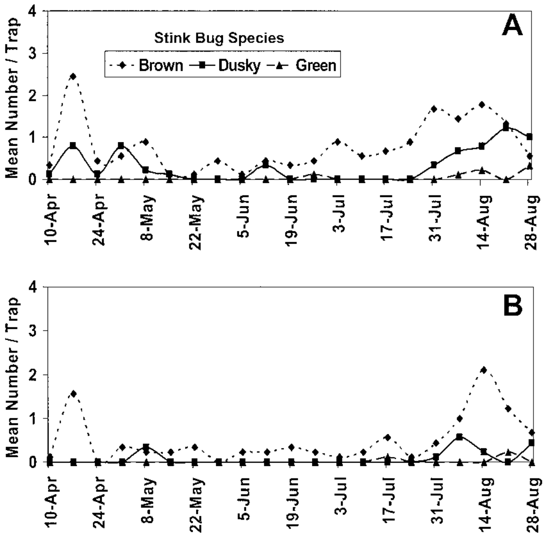

Fig. 4. Seasonal occurrence of brown, dusky and green stink bugs as determined with baited pyramid traps in a commercial (A) and abandoned (B) peach orchard in 2003.

0.7289), commercial peach ($F = 1.08$; df = 9, 20; $P = 0.4187$), and abandoned peach orchard ($F = 0.78$; df = 9, 20; $P = 0.6387$) (Table 2). Green stink bugs were more abundant in the commercial apple orchard, and captures in baited masonite pyramid traps were higher than all other trap types likely because of a location effect in the third replication, although the effect of replicate was not significant.

Based on mean capture across all baited pyramid trap types, stink bugs were detected at similar levels in apple orchards from April through August, followed by an increase in captures in September (Fig. 3). Brown stink bug was the most abundant species captured in the abandoned orchard throughout the trapping period (Fig. 3B), whereas in the commercial orchard, a sharp rise in the number of green stink bugs captured occurred in September to early October (Fig. 3A). Brown stink bug was the most abundant species captured throughout the trapping period, and peak captures occurred in April and from early or mid-July through August in both commercial and abandoned peach orchards (Fig. 4).

Pyramid Trap Color and Lure Comparison. The GLM was significant for captures in the peach orchard ($F = 5.30$; df = 2, 6; $P = 0.0473$) and plastic pyramid traps painted with industrial safety yellow paint captured significantly more stink bugs when baited with IPM Technologies, Inc., lures than with Suterra lures (Table 3). The GLM also was significant in the apple orchard ($F = 7.64$; df = 2, 6; $P = 0.0224$) and standard coroplast yellow plastic pyramid traps baited with IPM Technologies, Inc., lures captured significantly more stink bugs than plastic pyramid traps painted with industrial safety yellow paint and baited with Suterra lures. There was no significant difference between captures in standard coroplast yellow plastic pyramid traps and plastic pyramid traps painted with industrial safety yellow paint (each baited with IPM Technologies, Inc., lures) in both peach and apple orchards.

Tree and Weed Sampling. There was a significant positive correlation between mean number of stink bugs captured on a biweekly basis from 1 May to mid-October per baited pyramid trap and tree beating samples ($P = 0.0294$) in the commercial apple orchard; the correlation between baited pyramid trap and sweep net samples during the same interval also was positive, but not significant (Table 4). In the unmanaged apple orchard, there were significant positive

Table 3. Cumulative mean no. of stink bugs captured in plastic pyramid traps of two colors and baited with two lures in an apple and peach orchard in 2003

Orchard	Pyramid trap color	Lure type	n	Mean ± SE
Peach	Industrial Safety Yellow	IPM Technologies, Inc.	3	20.0 ± 5.66a[a]
	Industrial Safety Yellow	Suterra	3	5.0 ± 0.57b
	Standard Coroplast Yellow	IPM Technologies, Inc.	3	13.66 ± 0.88ab
Apple	Industrial Safety Yellow	IPM Technologies, Inc.	3	9.66 ± 2.33ab
	Industrial Safety Yellow	Suterra	3	2.33 ± 0.67b
	Standard Coroplast Yellow	IPM Technologies, Inc.	3	11.33 ± 1.76a

[a] Means within a column for each crop followed by the same letter are not significantly different ($\alpha = 0.05$; Tukey's HSD test).

Table 4. Pearson's correlation coefficients based on mean number of stink bugs captured per baited pyramid trap correlated with mean number captured per sample by either tree beating or sweep netting on each sampling date in sprayed and unsprayed apple and peach orchards in 2003

Orchard	Management regime	Sampling technique	n	Pearson's correlation coefficient	P value
Apple	Sprayed	Tree beating	13	0.6023	0.0294
		Sweep netting	13	0.4667	0.1079
	Unsprayed	Tree beating	13	0.9076	<0.0001
		Sweep netting	13	0.7463	0.0034
Peach	Sprayed	Tree beating	9	-0.2502	0.5156
		Sweep netting	9	0.5316	0.1407
	Unsprayed	Tree beating	10	0.5132	0.1292
		Sweep netting	10	0.5890	0.0732

correlations between mean number of stink bugs captured per baited pyramid trap and tree beating ($P < 0.0001$) and sweep netting ($P = 0.0034$) samples (Table 4). Within commercial and unmanaged peach orchards, there were no significant correlations between mean number of stink bugs captured on a biweekly basis from 1 May to late August per baited pyramid trap and tree beating and sweep netting samples. All correlations were positive with the exception of the correlation between pyramid trap and tree beating samples in the commercial peach orchard (Table 4).

Trapping Mechanism Studies. After introduction into pyramid trap jar tops, significantly more female and male brown stink bugs escaped than died throughout the 7 d test period. In the case of females, 58.4% escaped and only 20.8% died, whereas 66.7% of males escaped and only 26.7% died (Table 5). In jar traps, 100% of female and male stink bugs escaped or died 5 and 3 d after introduction, respectively. Although a greater percentage of both female and male stink bugs died in jar traps compared with pyramid trap jar tops, significantly more males escaped (66.7%) than died (33.3%). In the case of females, significantly more died (56.7%) than escaped (43.3%) (Table 5).

Discussion

For many phytophagous insects, pheromones serve as attractants for other conspecifics of the same or opposite sex (Cardé and Baker 1984). The *Euschistus* spp. aggregation pheromone, methyl (2*E*,4*Z*)-decadienoate (Aldrich et al. 1991) has been included in monitoring traps deployed in pecan (Yonce and Mizell 1997, Cottrell et al. 2000) and peach (Johnson et al. 2002) orchards in the southern United States. However, very little published data exist regarding the relative increases in captures of *Euschistus* spp. in traps baited with methyl (2*E*,4*Z*)-decadienoate compared with unbaited traps in orchards. In our studies, significantly more stink bugs were captured in baited pyramid traps compared with baited jar traps and unbaited pyramid and jar traps in commercial and unmanaged apple and peach orchards in 2003 (Table 2); a similar trend was observed in 2002, although captures were much lower (Table 1). These results point to the importance of methyl (2*E*,4*Z*)-decadienoate. Response of stink bugs to this olfactory stimulus was the primary factor responsible for trap captures. In fact, captures from baited pyramid and jar traps comprised 76 and 91%, respectively, of total trap captures in 2002, and 92 and 97% in 2003. One reason for increased captures in 2003 compared with 2002 was likely due to the type of commercial lure used. In a direct comparison of pyramid traps baited with either IPM Technologies, Inc., or Suterra lures, four times as many bugs were captured in traps baited with IPM Technologies, Inc., lures (Table 3). Because IPM Technologies, Inc., lures were loaded with 200+ mg of methyl (2*E*,4*Z*)-decadienoate with a release rate of ≈4 mg/d (as determined by the manufacturer), whereas Suterra lures contained only 100 mg of total material with an unknown release rate, it is likely that the larger amount of methyl (2*E*,4*Z*)-decadienoate loaded into IPM Technologies, Inc., lures resulted in a higher release rate or period of activity compared with Suterra lures, ultimately resulting in increased captures.

Pyramid traps coated with industrial safety yellow exterior latex gloss enamel paint captured more stink bugs than pyramid traps coated with other colors, including light and dark green, as well as a standard black pyramid trap and a pyramid trap covered with

Table 5. Mean number ± SE and percentage of alive, dead, or escaped female and male brown stink bugs after release into pyramid trap tops and jar traps at the end of the experimental period

Sex	Trap type	Exp. Period[a]	Escaped	Dead	Alive
Female	Pyramid	7	3.5 ± 0.3a[b] (58.4)[c]	1.3 ± 0.5b (20.8)	1.3 ± 0.5b (20.8)
	Jar	5	2.6 ± 0.2b (43.3)	3.4 ± 0.2a (56.7)	0.0 ± 0.0c (0.0)
Male	Pyramid	7	4.0 ± 0.6a (66.7)	1.6 ± 0.6b (26.7)	0.4 ± 0.2b (6.6)
	Jar	3	4.0 ± 0.6a (66.7)	2.0 ± 0.6b (33.3)	0.0 ± 0.0c (0.0)

[a] The no. of days until 100% released brown stink bugs had either escaped or died.
[b] Means within a row followed by the same letter are not significantly different ($\alpha = 0.05$; Tukey's HSD test).
[c] Indicates percentage.

aluminum foil (Mizell and Tedders 1995), indicating that hue or spectral reflectance of industrial safety yellow may be an attractive visual stimulus for foraging stink bugs. A large number of phytophagous insects respond positively to yellow, and this particular pigment is considered to be a supernormal foliage-type stimulus for foraging insects (Prokopy and Owens 1983). Thus, for stink bugs, classified as polyphagous feeders and hence as visual generalists (Prokopy and Owens 1978), an increased response to industrial safety yellow compared with other colors indicates a positive response to a supernormal foliage-mimicking stimulus, which one would predict for insects with a broad host range. However, visual response of stink bugs does not seem to be that specific in terms of variation in hue or percentage of spectral reflectance of yellow, because we compared captures in plastic pyramid traps coated with industrial safety yellow paint with unpainted standard coroplast yellow pyramid traps (each baited with IPM Technologies, Inc., lures) and found statistically equal numbers of captures in both apple and peach orchards (Table 3). Furthermore, the peak spectral reflectance wavelengths for industrial safety yellow and standard coroplast yellow were 600 and 599 nm, respectively, and overall reflectance curves were similar (Fig. 2), indicating that standard coroplast yellow pyramid traps are visually similar to other pyramid trap types coated with industrial safety yellow paint. The use of industrial safety yellow paint in association with jar traps did not improve trap efficacy, because captures in these traps were generally lower, although not significantly different from those in unpainted clear jar traps (Table 2). However, these results do not necessarily reflect a lack of response to the visual stimulus provided by industrial safety yellow paint in association with jar traps. Instead, because stink bugs apparently do not prefer to enter dark places (Mizell and Tedders 1995), reduced captures in painted jar traps could be due to the darkened trap interior that resulted from the addition of paint.

Brown stink bug represented an average of 58% of all stink bug captures when all sites and both years were combined, with dusky, green, and other stink bugs representing 20, 14, and 8%, respectively. These results are based on captures predominantly in traps baited with *Euschistus* spp. pheromone, methyl (2*E*,4*Z*)-decadienoate. In the eastern United States, brown stink bug is captured more frequently than other species when this pheromone is included in yellow pyramid traps deployed on the ground (Yonce and Mizell 1997, Johnson et al. 2002). This pattern, however, does not provide definitive information with regard to damaging potential of populations of each stink bug species and hence, need for insecticide application. In other words, brown stink bug could be the most prevalent species present in eastern fruit orchards and therefore is captured more frequently, or it could be less prevalent than other species, and trap captures were increased by the presence of methyl (2*E*,4*Z*)-decadienoate and trap deployment strategy. In fact, when pyramid traps baited with methyl (2*E*,4*Z*)-decadienoate were placed within the canopy of pecan trees (at heights of ≈9 m), more dusky than brown stink bugs were captured in Georgia (Cottrell et al. 2000). Thus, one would need a second measure of species abundance and frequency in eastern fruit orchards (such as tree beating or sweep net samples) to determine how accurately trap captures reflect species composition in orchard ecosystems. Therefore, in 2003, we conducted biweekly tree beating and sweep netting in all orchards and found that although we captured a large number of other pentatomid species, the ratios of brown, dusky, and green stink bugs present in these samples closely resembles that of trap captures. We included green stink bug as part of our sampling regime because it is an economically important pest species of tree fruit in this region (Hogmire 1995), although not necessarily the primary species attracted to baited pyramid traps because the bait itself is the *Euschistus* spp. aggregation pheromone. The ratios of brown, dusky and green stink bugs captured by baited pyramid traps were 63, 22, and 14%, respectively; by sweep netting were 60, 35, and 5%, respectively; and by tree beating were 49, 40, and 11%, respectively. Thus, captures in baited traps seem to reflect the overall species composition.

Also important, however, is the degree to which baited pyramid traps reflect stink bug abundance. In both commercial and unmanaged apple orchards, stink bugs were captured throughout the trapping period, but captures increased in late summer and peaked in August and September (Fig. 3). Trap captures seem to reflect species abundance very well based on significant positive Pearson's correlations between biweekly baited pyramid trap and tree beating samples in both commercial and unmanaged apple orchards, and biweekly pyramid trap and sweep netting samples in the unmanaged apple orchard (Table 4). Baited pyramid traps seem to provide an accurate assessment of population size of stink bugs in apple orchards. In commercial and unmanaged peach orchards, peaks in trap captures were recorded in early April and again in late July and August (Fig. 4). However, although there were positive correlations between biweekly captures in baited pyramid traps and tree beating and sweep netting samples, none were significant, indicating that trap captures were not as reliable a measure of population size in peach orchards (Table 4). Stink bugs are attracted to various weed and tree hosts based on succession of flowering and phenological development (McPherson and McPherson 2000). Because peach trees typically bloom in mid-April, before availability of other flowering species, these are likely a favorable early season host for overwintered adults. Thus, correlations between pyramid trap and sweep netting samples in peach orchards may not have been significantly correlated because of the early season peak in trap captures (Fig. 4), a time when other weedy hosts were not available resulting in reduced numbers recovered in sweep netting samples. Furthermore, as stink bugs are a key pest of stone fruit (Hogmire 1995), the rigorous spray program used in peach orchards (Anonymous 2002) could have been responsible for the lack of correlation with tree beating samples in the commercial peach orchard, although this does not explain the lack of a significant correlation in the unmanaged peach orchard.

Even though we did have significant positive correlations between baited pyramid trap captures and tree beating and weed sweeping samples in commercial and unmanaged apple orchards, we likely were underestimating the population size of stink bugs due to problems associated with the trapping mechanisms of pyramid trap jar tops. Cottrell (2001) demonstrated that inclusion of an insecticide ear tag (active ingredients included 10% λ-cyhalothrin and 13% piperonyl butoxide) in pyramid trap jar tops significantly increased captures in baited traps. However, Cottrell did not calculate the proportion of bugs that escaped after entry into trap tops, despite the presence of insecticide ear tags. In our studies, we released either six female or six male brown stink bugs into pyramid trap jar tops and jar traps baited with methyl (2*E*,4*Z*)-decadienoate and provisioned with one-fourth piece of insecticide ear tag (impregnated with 10% permethrin and 13% piperonyl butoxide), and found that after 7 d, 58% of females and 67% of males escaped from pyramid trap jar tops, and 43% of females and 67% of males escaped from jar traps. High rates of escape and poor kill of stink bugs with insecticide ear tags (Table 5) undoubtedly resulted in reduced captures in traps used in our study. Although Cottrell (2001) used a full ear tag and we deployed only one-fourth piece in our respective studies, we have recently compared a full ear tag with a one-fourth piece and observed no increase in trap captures (H.W.H., unpublished data). Thus, even though insecticide ear tags improve overall trap captures (Cottrell 2001), the true population size could be vastly underestimated due to a high proportion of stink bugs that potentially could escape from traps. A more effective trapping mechanism is needed to reduce escape or increase kill of stink bugs within the trapping device.

Other problems included those associated with pyramid traps constructed of plywood; they were frequently damaged by vertebrate pests, subject to discoloration from sooty mold, and prone to warp. However, because standard coroplast yellow pyramid traps seem to be visually similar (Fig. 2) and capture equal number of bugs as traps coated with industrial safety yellow paint (Table 3), these traps could provide a practical alternative. Finally, and perhaps most importantly, if pyramid traps are to be used as a predictive tool, one must be able to identify damage caused by stink bugs. This has proven difficult in apple due to similarity in appearance to the physiological disorders cork spot (Brown 2003) and bitter pit (Ohlendorf 1999). Thus, if trap efficacy is to be firmly established, damage by stink bugs must be able to be distinguished from these physiological disorders in a reliable manner. Efforts to identify simple diagnostics for separating damage inflicted by stink bugs revealed that stink bug damage differs from cork spot in three ways: 1) there is a gradual rather than an abrupt edge along the depression created by stink bug feeding on the fruit surface, 2) corky tissue is found immediately beneath the skin of stink bug feeding sites, and 3) there is a puncture site present (Brown 2003).

In conclusion, baited pyramid traps captured the greatest number of stink bugs, and predominantly brown stink bugs. The presence of methyl (2*E*,4*Z*)-decadienoate deployed in association with pyramid traps was necessary to attract large numbers of brown and dusky stink bugs. However, the apparent visual cue provided by industrial safety yellow paint was not, because standard coroplast yellow pyramid traps captured statistically equal numbers of stink bugs. Although captures in baited pyramid traps were significantly correlated with tree beating samples in commercial and unmanaged apple orchards, and with sweep netting samples in an unmanaged apple orchard, this was not the case in peach orchards. Problems associated with the trapping mechanism of pyramid trap jar tops must be corrected to accurately assess population size and develop an effective monitoring tool for stink bugs in mid-Atlantic orchards.

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